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The detailed and biologically realistic neural model of architectures that utilize Gabor filters for vision computations continues to be the focus of research. Additionally, some further testing of a three layer back-propagation learning network for computing slant/tilt was undertaken. A model has been developed which simulates the process of texture segmentation in the visual cortex according to the computational model of M.R. Turner et.al. using the McGregor high-fidelity neural simulator. This system attempts to faithfully simulate the transfer functions of neurons using various numerical simulation methods.

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Annual Progress Report: AFOSR Grant 88-0296

R. Bajcsy, G. Gerstein

November 4, 1991

The AFOSR grant has been active since September 1, 1988. This progress report describes the activities which have been partially supported by this grant from the date September 1, 1990 to September 1, 1991.

1 Overview

The detailed and biologically realistic neural model of architectures that utilize Gabor filters for vision computations continues to be the focus of research. Additionally, some further testing of a three layer back-propagation learning network for computing slant/tilt was undertaken.

1.1 Texture Segmentation Using Neuronal Simulations

A model has been developed which simulates the process of texture segmentation in the visual cortex according to the computational model of M.R. Turner et.al. using the McGregor high-fidelity neural simulator. This system attempts to faithfully simulate the transfer functions of neurons using various numerical simulation methods. In the segmentation model, we have sixteen neural pools which correspond to sixteen kinds of Gabor filters, tuned to four spatial frequencies and four orientations. Neurons in a pool are arranged into arrays according to their spatial locations. There are both excitatory and inhibitory interconnections among neurons in the same pool. When a neuron

is firing, it emits excitatory and inhibitory signals to the neurons around it. E represents a neuron's "total excitatory energy", i.e, E is the sum of excitatory strengths of connections to that neuron. I represents the "total inhibitory energy"; all the neurons in this network model have identical connection arrangements.

There also exist interactions among neurons with similar spatial locations, but in different pools. Such interactions are presumably much weaker than the interactions inside a pool. They are arranged so that neurons with relatively similar specificity excite each other and neurons with quite different specificity inhibit each other.

We tested segmentation for many texture images, from regular patterns to complex natural images. With appropriate E/I values, all texture images we tested can be segmented; the optimal sets of E/I values fall in the same range for most images.

The success and convergence time of the network depends on E/I. If E/I is small, only texture boundaries could be represented in the network; for large values of E/I, one can get fine segmentation of the tested image. Actually, these activations of neurons in the neural network continuously change with E/I.

Obviously, the success of image segmentation depends on the texture structure; for textures with higher density and more regularity, a more extensive set of E/I can be applied to segment the texture; for irregular, low density textures, it is often hard to get a boundary representation, and segmentation can only be obtained for a relatively narrow set of E/I.

The network was fairly robust relative to the above parameters. For all images we tested, when varying the distributions of excitatory and inhibitory strengths with distance, while keeping E/I unchanged, the noise during the evolution of the segmentation would change slightly, but the final segmentations were not affected.

The computation time of the network is quite rapid. The time required to converge to a segmentation varies with texture structures; regular, high density textures need less time to be segmented. Generally, for most tested images, the boundary or segmentation can appear in 60–120ms, and becomes stable after 150ms.

A realization of the above network on a parallel computer combined with the Connection Machine Gabor Filter Convolution Algorithm, which is implemented on the GRASP Laboratory's Connection Machine, could yield a

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very fast texture segmentation system.

So far we have shown that texture segmentation could be achieved with a simple, feedforward network with lateral connections. We continue to work on the problem of using feedback or neural clustering for neural pools with similar firing patterns, as well as the question of how to combine the outputs of the sixteen pools.

1.2   Three Layer Network

Further experimentation has been attempted on a three layered backpropagation network. The network has previously been shown to generalize to different contrast levels within a given training set of natural and synthetic images. We then attempted to train the network on synthetic sinusoidal imagery with unimodal frequency and orientation power content. The learning curve for the network showed that the network had indeed generalized the computation for this material. However, when the same network was used to process images with naturally occurring textures, its performance was poor. From this we conclude that such an approach has poor noise immunity in terms of input textures that are highly irregular and thus has highly variable spatial frequency content, especially relative to the iterative relaxation algorithms of Turner et.al. Some modifications of the network topology might be in order to deal with this limitation.

2   Publications

The papers are briefly described below:

1. Estimation of textured surface inclination by parallel local spectral analysis. Accepted for publication in *The International Journal of Computer Vision*[1].

   This paper describes a cooperative algorithm for estimating the inclination of planar textured surfaces from the two

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[1] Still undergoing revision

dimensional distributions of Gabor filter amplitudes. An analytic model is first developed for these two dimensional distributions. Using this model, a hill climb algorithm is able to estimate the inclination of textured surfaces. The algorithm may be viewed as operating in parallel on a number of image patches and consolidating a global inclination value by lateral propagation of local estimates between regions.

2. Underestimation of textured surface inclination by human observers: A model. *Biological Cybernetics*, in press.

Since the experiments of Gibson in the 1950's it has been known that, with monocular stationary views, human subjects in psychophysical experiments will tend to underestimate the inclination of textured surfaces. This is particularly true when the textures are perceived as being "irregular". Two dimensional distributions of Gabor amplitudes from images of such surfaces are frequently altered in ways consistent with regular textures at lower angles of inclination. The cooperative algorithm described in the annual report exhibits the same underestimation behavior as humans, suggesting that a similar computation may be occurring in the visual cortex.